

# XTE J1739–302 as a Supergiant Fast X-ray Transient

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## ABSTRACT

XTE J1739–302 is a transient X-ray source with unusually short outbursts, lasting on the order of hours. Here we give a summary of X-ray observations we have made of this object in outburst with the *Rossi X-ray Timing Explorer (RXTE)* and at a low level of activity with the *Chandra X-ray Observatory*, as well as observations made by other groups. Visible and infrared spectroscopy of the mass donor of XTE J1739–302 are presented in a companion paper. The X-ray spectrum is hard both at low levels and in outburst, but somewhat variable, and there is strong variability in the absorption column from one outburst to another. Although no pulsation has been observed, the outburst data from multiple observatories show a characteristic timescale for variability on the order of 1500–2000 s. The *Chandra* localization (right ascension  $17^{\text{h}}39^{\text{m}}11.58^{\text{s}}$ , declination  $-30^{\circ}20'37.6''$ , J2000) shows that despite being located less than  $2^{\circ}$  from the Galactic Center and highly absorbed, XTE J1739–302 is actually a foreground object with a bright optical counterpart. The combination of a very short outburst timescale and a supergiant companion is shared with several other recently-discovered systems, forming a class we designate as Supergiant Fast X-ray Transients (SFXTs). Three persistently bright X-ray binaries with similar supergiant companions have also produced extremely short, bright outbursts: Cyg X–1, Vela X–1, and 1E 1145.1–6141.

*Subject headings:* X-rays:individual(XTE J1739-302) — X-rays:binaries — supergiants — stars:neutron

## 1. Introduction

Most bright X-ray transients last for weeks, and come from two kinds of systems: low-mass X-ray binaries where the compact object is either a black hole or a neutron star with a low magnetic field (X-ray novae), and neutron star binaries with a high-mass, Be-type companion (Be/NS). In the latter systems, the neutron star is usually in a wide, ec-

centric orbit, and the outbursts often occur at regular intervals, separated by the orbital period, and generally close to periastron. These two classes can be distinguished from each other by neutron star pulsations, by optical observations of the companion to determine the compact object's mass, by regularity of recurrence (which indicates a Be/NS binary), or by their X-ray spectra.

On 12 August 1997, a new X-ray transient near the Galactic Center, XTE J1739–302, was discovered and localized using two serendipitous scans by the *Rossi X-ray Timing Explorer (RXTE)*, about 2.5 hr apart and in nearly perpendicular directions (D. M. Smith et al. 1998). Null results from other *RXTE* exposures to the field limited its duration to less than 11 dy. Although this is unusually short for a Be/NS binary outburst, and although no pulsations were detected despite a very high sensitivity to periods up to 300 s, we concluded that the system was probably a Be/NS system with

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a long spin period and short outburst duration. This conclusion was based primarily on the X-ray spectrum, which was well fitted by an optically thin thermal bremsstrahlung spectrum of temperature  $(21.6 \pm 0.8)$  keV, a spectral form typical of X-ray pulsars such as Be/NS systems. The hydrogen column derived from the same *RXTE* spectrum,  $(6.2 \pm 0.2) \times 10^{22} \text{ cm}^{-2}$ , was consistent with absorption along the line of sight to the Galactic Center, reinforcing the conclusion that this was indeed a source in the Galactic bulge – in which case it was also unusual as a Be/NS outburst in its relatively high luminosity.

In this paper, we summarize all the X-ray observations of this system to date, revealing variations in spectrum, luminosity, and absorption column. We discuss the initial identification of the counterpart in the United States Naval Observatory (USNO) and Two Micron All Sky Survey (2MASS) catalogs.

In the companion paper (Negueruela et al. 2005a, hereafter Paper II) we discuss the results of detailed optical and infrared spectroscopy of the companion. Both of our original conclusions – that this is a Be/X-ray system and that it is located in the Galactic bulge – are incorrect. The companion is a highly reddened blue supergiant in the foreground, and the absorbing material is local to the system (Paper II). XTE J1739–302 is therefore an unusual system in having a blue supergiant companion and very brief outbursts. We conclude with a discussion of the connection of this object with other sources that have similar properties, defining a new subclass of high-mass X-ray binary system. We also discuss the possibility that the same flaring process is active in three continuously bright binaries that also have short outbursts and blue supergiant companions: Cyg X–1, Vela X–1, and 1E 1145.1–6141.

## 2. Observations

Table 1 shows a summary of observations of outbursts of XTE J1739–302, along with the two sensitive observations made by focusing X-ray observatories. Most of the outbursts discovered so far have been the result of two long-term studies with *RXTE*, neither of them specifically directed toward this system.

### 2.1. Outbursts from the 1E 1740.7–2942 campaign

Since the start of *RXTE* operations in 1996, we have been observing the black-hole candidate 1E 1740.7–2942 regularly (Smith, Heindl & Swank 2002, and references therein), starting at monthly intervals and gradually increasing over the course of the mission to twice per week. The field of view of the *RXTE* pointed instruments when observing 1E 1740.7–2942 includes XTE J1739–302, at an off-axis position corresponding to a response of 20% relative to the center of the field (because of the need to avoid other sources in the region, 1E 1740.7–2942 itself is placed at a relative response of 43%). XTE J1739–302 was first discovered because *RXTE* slewed almost directly across it during an outburst as it approached the 1E 1740.7–2942 field on 12 August 1997. Just 2.5 hr previously, a scan that was part of a program to survey the Galactic plane (Valinia & Marshall 1998) passed over the active XTE J1739–302 as well, allowing a two-dimensional localization to 4.8' accuracy (99% confidence; but see §2.4 below).

Because XTE J1739–302 remained in the field of view during the whole 1300 s of the pointing toward 1E 1740.7–2942, this episode also gave us the first good spectral and timing data from XTE J1739–302 (D. M. Smith et al. 1998). We have identified two other major outbursts in the series of pointings to 1E 1740.7–2942, in 2000 November and 2002 June. Figure 1 shows a differential lightcurve of the PCA count rate in the 1E 1740.7–2942 pointings since the start of 1997 – each point has had the average of its two immediate neighbors subtracted out to remove the slow variations intrinsic to 1E 1740.7–2942. The count rates shown are from the Proportional Counter Array (PCA) instrument, in the energy range 2.5–25 keV, normalized to a single proportional counter unit (PCU) and using the first xenon layer of the detectors only. Detector PCU0, which suffered a puncture in the middle of the mission, degrading its performance, is not used after that event. The transient outbursts we report were visible in all PCU units that were on at the time of observation. Instrumental background was subtracted using the “cmfaintL7” model, which is accurate to about 2%, (Jahoda et al. 2005); the typical count rate due to 1E 1740.7–2942 is on same

order as the background. Galactic diffuse emission, which is significant below 10 keV, was estimated by pointing to a blank field nearby (Main et al. 1999). Since this emission is constant it is irrelevant to the differential lightcurve in Figure 1, but it is important for spectroscopy.

Two points stand out: the discovery outburst early on, and a bright outburst in 2002. We give the two moderately high points nearer the middle of the plot two very different interpretations. The second of them involves not just an increase in high energy counts in the 1E 1740.7–2942 field but also a decrease in low energy counts – we therefore take it to be a brief, unusual, temporary change in spectral state of 1E 1740.7–2942 (Smith, Heindl & Swank 2002). The earlier of these two points at around 200 c/s/5PCU, however, is consistent with an additional spectral component added on top of the average 1E 1740.7–2942 spectrum from the previous and subsequent several pointings. The lightcurve of this pointing is similar to the two very bright outburst pointings in that it has significant low-frequency noise, which is never the case with 1E 1740.7–2942 in its hard state (Figure 2). If the expected 1E 1740.7–2942 contribution is subtracted and the presumed XTE J1739–302 spectrum is fit, it shows extremely high absorption (Table 1). The unabsorbed luminosity of this outburst is then actually comparable to the other two events in this survey, although its raw count rate is much lower.

Table 2 shows the result of fitting each of these three PCA outbursts from 2.5–25 keV with the optically thin thermal bremsstrahlung model from Kellogg, Baldwin & Koch (1975) as provided by XSPEC (Arnaud 1996). Lutovinov et al. (2005) found that the thermal bremsstrahlung curve we fit to the first major outburst observed by *RXTE* (D. M. Smith et al. 1998) also fit perfectly to the *Integral*/IBIS/ISGRI data from the outbursts on MJD 52877 (26 August 2003) and MJD 52888 (see Table 1). Together, these results suggest that the intrinsic spectra in outburst are relatively consistent, although the amount of local absorbing material is highly variable. Using the distance to XTE J1739–302 of 2.3 kpc derived photometrically in Paper II, the bright outbursts peak at a few  $\times 10^{36}$  erg s $^{-1}$  in unabsorbed luminosity from 1–200 keV (Table 2).

## 2.2. Outbursts from the Galactic bulge scan campaign

The PCA Galactic bulge scan campaign (Swank & Markwardt 2001) has taken data approximately every three days since 5 February 1999. Although spectral and fast-variability information are not obtained from these data, the identification of the outbursts with a particular source is much more secure, since the instrument’s one-degree field of view is scanned rapidly over the Galactic center region. Figure 3 shows the lightcurve for XTE J1739–302 from this campaign. There is only one outburst whose order of magnitude is the same as the three bright outbursts found in the 1E 1740.7–2942 campaign since 1996. Since we cannot derive an absorption column for this event, we do not know if it is bright but highly absorbed or somewhat fainter than the other three. The superior ability of the scanning technique to distinguish between small outbursts from this source and small changes in 1E 1740.7–2942 has allowed the identification of many much smaller outbursts (Table 1, section 2). It is possible that any number of the outbursts from the bulge scans might have been highly absorbed like the 2000 November event and therefore much more luminous than their count rate indicates.

## 2.3. Outbursts from *Integral*

XTE J1739–302 was later observed in outburst in Galactic bulge data from the *Integral* satellite (Sunyaev et al. 2003a; Lutovinov et al. 2005). Data products from three *Integral* observing seasons of the Galactic bulge are now publicly available from the *Integral* Science Data Centre (ISDC). Figure 4 shows lightcurves from the IBIS/ISGRI instrument over these three seasons, summed from 13–71 keV. There is one very significant, multi-point flare in each season, and a number of minor peaks from 5 to 10 counts per second. Lutovinov et al. (2005) show an additional outburst around MJD 52888.3, with about half the peak flux of the event on MJD 52877 and a shorter duration. This interval is not available in the public data set shown in Figure 4. Sguera et al. (2005) show much more detailed lightcurves of the outburst (or series of outbursts) on 53073/4. The *Integral* feature on MJD 52895 in Figure 4 is only a single point with a larger than normal er-

ror bar, so we are not including it in our catalog of outbursts.

Two of the minor outbursts in the *RXTE*/PCA bulge scan data come just after major outbursts measured by *Integral*, suggesting that some of the other “minor outbursts” in the *RXTE* bulge scans may also be part of the decay or rise phase of larger events.

The observation reported by Sunyaev et al. (2003a) is in the center panel of Figure 4, and is the longest in duration and fluence. The time structure of this event was shown by Lutovinov et al. (2005) and is also shown in Figure 5. Because *Integral*’s coverage is much more continuous during an observing season than *RXTE*’s, it is the *Integral* observations that show us the true characteristic durations of outbursts from XTE J1739–302, from about 2 hr to about half a day.

#### 2.4. *Chandra* observation

We observed XTE J1739–302 with the ACIS-I CCD on *Chandra* on 15 October 2001, for 5 ksec in Timed Exposure (TE) mode. The observation was not made in response to any outburst, but was scheduled at the convenience of the observatory. We found about 0.25 counts per second from the only significant point source in the field of view. The position of this object is shown in Figure 6. It falls within the quoted error circles from *ASCA* (Sakano et al. 2002, 90% confidence) and *Integral* (Lutovinov et al. 2005, confidence level not quoted). It falls barely outside the 99% confidence levels from *RXTE* in the 1997 outburst (D. M. Smith et al. 1998) and the 2001 outburst. We note, however, that *RXTE* is not an imaging instrument, nor were the slews we used to produce these localizations optimized for the purpose, as are those of the Galactic bulge campaign (Swank & Markwardt 2001). The 99% confidence limit for 1997 was based on a set of simulations of the effect of intrinsic variations in the count rate of the source. These variations can distort the position derived from a slew, which also relies on a time-varying count rate. The 99% confidence limit was based on an assumption that the intrinsic source variation during the slew was no bigger than the variations observed in 1300 s of subsequent pointing to the source. If this assumption was violated, that confidence limit was too restrictive. The circle shown for 2001 simply repeats the uncertainty

derived from the 1997 outburst.

Although the observed count rate would normally cause moderate pileup in ACIS-I, the source turned out to be 4’ from the pointing axis. The point-spread function at that distance is broad enough to spread the image over many more pixels than would have been the case on axis. Separate spectra taken from the core and wings of the image were consistent with each other, indicating that there is no problem with pileup. The *Chandra* spectrum was well fit by a hard power law (see Table 1). When we attempted to fit it with the thermal bremsstrahlung spectrum that matched the *RXTE* data in outburst (Table 2), we found that the limited energy range of *Chandra* did not allow us to constrain the temperature. The same problem appeared when the *RXTE* data were artificially constrained to the same energy range (below 10 keV). But the power law fits in this restricted range show that the low-level emission was harder than the outburst emission (Table 1).

In the 2–10 keV band the unabsorbed luminosity is  $8 \times 10^{33}$  erg s<sup>−1</sup> at 2.3 kpc. Assuming a spectrum identical to the 1997 outburst, the bolometric luminosity in X-rays of all energies would be 2.8 times higher. Because we cannot see where the *Chandra* spectrum starts to turn over, we do not know if the true bolometric luminosity was somewhat more or less than this value. As pointed out by in’t Zand (2005), the state we observed with *Chandra* is not “quiescent”, even though no attempt was made to trigger on an outburst. The *ASCA* upper limit (see below) is, after all, an order of magnitude lower than the *Chandra* flux; and the observation by in’t Zand (2005) of the similar source IGR J17544–2619 in quiescence showed a much lower flux and a very soft spectrum, entirely different from the hard spectra seen by *Chandra* and *RXTE* for XTE J1739–302.

The lightcurve, shown in Figure 2, has a root mean square (rms) variability of 36.5%, compared to an expectation of 35.2% from Poisson noise, using the binning time of 32.41 s shown in Figure 2. In the absence of any nonuniformity in the instrumental response over the course of the observation, this suggests an intrinsic rms variability of 10%. Fourier analysis of the lightcurve shows no significant pulsations.

The position derived from this *Chandra* pointing was right ascension = 17<sup>h</sup>39<sup>m</sup>11.58<sup>s</sup>, declina-

tion =  $-30^{\circ} 20' 37.6''$ , J2000 (Smith et al. 2003a; Smith & Heindl 2004); it enabled us to search for the optical counterpart of the system (see below).

## 2.5. Upper limits

The single upper limit shown in Table 1, from *ASCA* (Sakano et al. 2002), is included because it is the deepest such limit for this source, and because it occurred in the same observation that fortuitously saw the start of a major outburst (MJD 51248.3, Table 1) immediately afterward. Due to the variable absorption column from XTE J1739–302, we cannot use this upper limit to directly place a limit on the unabsorbed flux. Although the source was much fainter than when observed by *Chandra*, we cannot say whether this was due to a higher absorption column or intrinsically fainter emission. However, by assuming that the absorption column was the same as during the outburst immediately following, Sakano et al. (2002) found the  $3\sigma$  upper limit for the observed flux shown in Table 1. Removing the effect of absorption and placing the source at 2.3 kpc (Paper II), this corresponds to  $7.0 \times 10^{32}$  erg s $^{-1}$  at 2.3 kpc.

The fact that this source was not discovered prior to 1997 puts implicit upper limits on the frequency of its outbursts. Figure 1 suggests a duty cycle of  $\sim 1\%$  for the bright outbursts from most of the pointings of *RXTE* to 1E 1740.7–2942; the *RXTE* bulge scans (Figure 3) and *Integral* (Figure 4) are better able to separate sources, and suggest that there is a continuous range of outburst luminosities from the upper limit seen with *ASCA* to the low level seen with *Chandra* up to the brightest outbursts observed.

A series of explicit upper limits dating from 1988 to 1996 were reported by Aleksandrovich et al. (1998) in a retrospective analysis of data from the TTM coded-mask X-ray telescope, part of the *Roentgen Astrophysical Observatory* on the Kvant module of the Mir space station. These upper limits are quoted as ranging from 9–30 mCrab during 21 different pointing series. Each series consisted of a number of pointings spread over an interval varying from about a day to a month. Due to the very short duration of outbursts from this source, the upper limits that are summed from the more widely spread series may not be as meaningful as the ones based on data taken during a single day.

## 3. Discussion

### 3.1. Identification of the mass donor

The *Chandra* position derived for XTE J1739–302 is approximately  $0.65''$  from a bright star in the USNO B1.0 catalog, 0596–0585865 (0525–28760590 in the USNO A2.0 catalog). The red and blue magnitudes in the first USNO epoch (R1 and B1) are 13.16 and 17.32, respectively, and in the second epoch (R2 and B2) are 12.93 and 16.97. This star is also a bright 2MASS source, 17391155–3020380, with  $J=8.60$ ,  $H=7.82$ , and  $K=7.43$ .

Figure 7 is a raw color/magnitude diagram of USNO A2.0 stars within  $1'$  of the *Chandra* position. The star that is consistent with the *Chandra* position is marked with a box; it is a very bright and very red star for the field. A statistical analysis of a larger field ( $3'$  in radius) gives the probability of any USNO A2.0 star coming within  $0.65''$  of the *Chandra* position by chance as  $2.3 \times 10^{-3}$ . The probability of such a coincidence with a star as bright as 0525–28760590 is  $3.5 \times 10^{-5}$  and the probability of coincidence with a star with as red a B–R color as 0525–28760590 is  $3.5 \times 10^{-6}$ .

Followup spectroscopy of this star was taken in the visible and in the infrared by two of us (IN and TEH, respectively), and is reported in detail in Paper II. The brightness of the companion demands a location closer than the Galactic bulge, despite the position of the source within  $2^{\circ}$  of the Galactic Center and its high X-ray absorption. Paper II gives a distance estimate of 2.3 kpc based on the new spectroscopy and photometry.

### 3.2. A characteristic timescale of variability?

There have been no pulsations reported from any of the outbursts in Table 1, with very strong upper limits up to a period of 300 s from the first reported outburst (D. M. Smith et al. 1998). The *ASCA* outburst of 1999, caught at its very beginning, showed 2 peaks with a deep valley between them, separated by approximately 1500 s (Sakano et al. 2002). It is worth noting that all three outburst lightcurves in Figure 2 have a variation consistent with that period, although it is very close to the duration of the observation. Lightcurves of several of the *Integral* outbursts in Sguera et

al. (2005) show peaks separated by approximately 2000 s. Since the duration of the outbursts is only a few times this period, it is difficult to ascertain whether there is a true pulsar spin period in this range or whether this is just a typical timescale of whatever drives the outburst. Either a much larger database of events or a serendipitous observation of a particularly long outburst will probably be needed to resolve this question.

### 3.3. Fast transients and supergiant companions

Yamauchi et al. (1995) discovered a transient source in the Scutum region with *ASCA*, designated AX 1845.0-0433, that turned on abruptly in the middle of the observing interval, showing violent variations for several hours until the pointing ended. This behavior was remarkably similar to the *ASCA* observation of XTE J1739-302 several years later (Sakano et al. 2002). Like XTE J1739-302, this object had a very hard spectrum in outburst, reminiscent of an X-ray pulsar, but no pulsations were observed. Coe et al. (1996) found an O9.5I supergiant within the *ASCA* error circle that they identified as the counterpart.

Two X-ray transients recently discovered with *Integral* also have very fast timescales: IGR 17544-2619 (Sunyaev et al. 2003b) and IGR 16465-4507 (Lutovinov et al. 2004). Both have blue supergiant companions, estimated as spectral type O9Ib and B0.5I, respectively (Pellizza, Chaty & Negueruela 2005; Negueruela et al. 2005b). The similarities of both to XTE J1739-302 in X-ray behavior and photometry led us to predict a blue supergiant companion for the latter source (Smith 2004), which we later confirmed spectroscopically (Negueruela et al. 2005b). Rough distance estimates based on photometry have been published for these systems: 3.3, 8.5, and 12.5 kpc for XTE J1739-302, IGR 17544-2619, and IGR 16465-4507 respectively (Smith 2004) and 3.6 kpc for AX 1845.0-0433 (Coe et al. 1996) (see Paper II for the derivation of the improved value of 2.3 kpc for XTE J1739-302). These four systems seem similar enough to classify them as a new subclass of high-mass X-ray binary, which we designate Supergiant Fast X-ray Transients (SFXT). in't Zand et al. (2004) also pointed out the growing connection between fast variability and probable wind accretion.

The unknown mechanism that drives the fast outbursts may be at work in other systems as well. Three persistently bright X-ray binaries with blue supergiant donors have recently been reported to show extremely bright outbursts far beyond their normal luminosity, lasting on the order of hours: pulsars Vela X-1 (Laurent et al. 1995; Krivonos et al. 2003) and 1E 1145.1-6141 (Bodaghee, Mowlavi, & Ballet 2004), and Cyg X-1, the canonical black-hole binary, which has shown six such events (Golenetskii et al. 2003). This suggests that the mechanism of this sort of fast outburst is not specific to the nature of the compact object. It may lie either in a sudden expulsion of material from the companion (in't Zand (2005) discusses the possible role of a clumpy wind) or an instability particular to the small accretion disks expected in a wind-accreting binary. The great differences in persistent flux between the SFXT sources like XTE J1739-302 and the bright sources that also flare quickly may lie in the size of the orbit or the level of activity in the companion; from what is known or deduced about the orbits and winds of these systems, however, there is not yet any clear correlation with persistent X-ray emission.

The large and variable local absorption in some of the systems may eventually provide a clue to the outburst mechanism. Vela X-1 shows a similar broad range of high absorption column values to XTE J1739-302 (Nagase et al. 1986). Cyg X-1 has a much lower absorption column (usually below  $10^{22}$  cm<sup>-2</sup>), which varies over about a factor of four with the orbital phase of the binary (Kitamoto et al. 2000, who also suggest that partial covering by a clumpy wind provides a better spectral fit than a simple absorption model). There have been no published observations of the large outbursts of Vela X-1, Cyg X-1 or 1E 1145.1-6141 using instruments sensitive below 10 keV that can measure absorption.

Not every fast X-ray transient can be put into the SFXT category. Flare stars and RS CVn systems have long been known to produce short X-ray flares, but these tend to have softer spectra and a nearly isotropic distribution, demonstrating that they are nearby (e.g. Pye & McHardy 1983; Castro-Tirado et al. 1999). X-ray superbursts can also have durations comparable to SFXT flares, but they generally occur on neutron stars that

produce ordinary Type I X-ray bursts and can be recognized by their characteristic luminosity, lightcurve, and long recurrence time (Cornelisse et al. 2000). There have also been short outbursts from three unusual X-ray binary systems that do not have the same sort of companions as the SFXTs: CI Cam (D. A. Smith et al. 1998), V4641 Sgr (Revnitsev et al. 2002), and A 0538–66 (White & Carpenter 1978). The outbursts from the former two systems were highly super-Eddington, which distinguishes them from the events discussed here, and were never repeated; the last, a well-known but mysterious system, is thought to be an extreme short-period Be/X-ray binary, and has shown the regular, periodic outbursts often seen in that class.

The 4.7 s pulsar AX J1841.0–0536, discovered by Bamba et al. (2001) with *ASCA*, showed flaring by a factor of 10 with a rise time of about 1 hr, and the authors proposed that it might be a new member of the same class as XTE J1739–302 and AX 1845.0–0433; *Integral* later detected a flare with a 10-minute risetime that may have come from the same system (Rodriguez et al. 2004; Halpern & Gotthelf 2004). Halpern et al. (2004) used *Chandra* to identify the counterpart of AX J1841.0–0536, which they reported as having features of the B spectral class. They also observed a weak, double-peaked H $\alpha$  profile, which they used to identify the companion as a Be star. This feature can also appear in interacting OB supergiants, however, and Halpern et al. (2004) did not report any diagnostics of the luminosity class of the system. SAX J1818.6–1703 (in’t Zand et al. 1998), XTE J1901+014 (Remillard & Smith 2002), and AX J1749.1–2733 (Grebenev 2004) are all fast transients whose optical counterpart is unknown, as was recently pointed out by in’t Zand (2005). Now that a tentative connection has been made between supergiant companions and fast variability, detailed study of the unclassified optical counterparts to all these systems should be a high priority.

**Note to be added in proof:** *The recent association of short, hard gamma-ray bursts with older stellar populations in galaxies at  $Z \sim 0.2$  (Fox et al. 2005), and the strengthening of the NS/NS or NS/BH merger hypothesis for these events, encourages a search for the progenitors of these systems. Although we are just beginning to study how*

*numerous the SFXTs might truly be, they seem to be a good candidate for the parent population.*

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TABLE 1  
SUMMARY OF X-RAY OBSERVATIONS OF XTE J1739–302

MJD	Instrument	PCA Rate c/s <sup>a,b</sup>	Absorbed Flux <sup>b</sup> $\times 10^{-11}$ erg/cm <sup>2</sup> /s	Unabsorbed Flux <sup>b</sup> $\times 10^{-11}$ erg/cm <sup>2</sup> /s	$n_H$ $\times 10^{22}$ cm <sup>-2</sup>	Power law index <sup>c</sup>	Minimum duration (hr)	Maximum duration (dy)	Ref. <sup>d</sup>
Major Outbursts:									
50672.7	<i>RXTE</i> /PCA <sup>e</sup>	638	169	260	$7.11 \pm 0.31$	$1.66 \pm 0.03$	2.5	11	[1]
51248.3	<i>ASCA</i> /GIS	...	200	236	$3.17^{+0.33}_{-0.31}$	$0.80^{+0.10}_{-0.11}$	0.6	3.6	[2]
51849.2	<i>RXTE</i> /PCA <sup>e</sup>	139	38	155	$36.8 \pm 4.2$	$2.04 \pm 0.20$	0.3	3.9	...
51977.9	<i>RXTE</i> /PCA <sup>f</sup>	179	...	...	...	...	...	2.9	...
52452.9	<i>RXTE</i> /PCA <sup>e</sup>	585	177	257	$6.37 \pm 0.42$	$1.55 \pm 0.04$	0.3	4.9	...
52720.5	<i>Integral</i> /IBIS	...	...	...	...	...	1.8	0.08	[3]
52877.8	<i>Integral</i> /IBIS	...	...	...	...	...	14	0.6	[4]
52888.3	<i>Integral</i> /IBIS	...	...	...	...	...	7	0.3	[5]
53073.28 <sup>g</sup>	<i>Integral</i> /IBIS	...	...	...	...	...	0.5	0.02	[3]
53073.48 <sup>g</sup>	<i>Integral</i> /IBIS	...	...	...	...	...	2	0.12	[3]
53074.08 <sup>g</sup>	<i>Integral</i> /IBIS	...	...	...	...	...	1.3	0.05	[3]
53569.7	<i>RXTE</i> /PCA <sup>f</sup>	251	...	...	...	...	...	3.0	...
Minor Outbursts:									
51265.80	<i>RXTE</i> /PCA <sup>f</sup>	67	...	...	...	...	...	7.0	...
51338.45	<i>RXTE</i> /PCA <sup>f</sup>	54	...	...	...	...	...	7.3	...
51660.76	<i>RXTE</i> /PCA <sup>f</sup>	41	...	...	...	...	...	7.8	...
51677.68	<i>RXTE</i> /PCA <sup>f</sup>	47	...	...	...	...	...	8.9	...
52043.77	<i>RXTE</i> /PCA <sup>f</sup>	34	...	...	...	...	...	6.9	...
52107.51	<i>RXTE</i> /PCA <sup>f</sup>	49	...	...	...	...	...	6.9	...
52350.98	<i>RXTE</i> /PCA <sup>f</sup>	38	...	...	...	...	...	8.0	...
52465.63	<i>RXTE</i> /PCA <sup>f</sup>	60	...	...	...	...	...	5.9	...
52720.90	<i>RXTE</i> /PCA <sup>f,h</sup>	80	...	...	...	...	...	7.0	...
52727.87	<i>RXTE</i> /PCA <sup>f</sup>	63	...	...	...	...	...	6.8	...
52779.67	<i>RXTE</i> /PCA <sup>f</sup>	45	...	...	...	...	...	6.8	...
52945.06	<i>RXTE</i> /PCA <sup>f</sup>	37	...	...	...	...	...	6.8	...
53074.05	<i>RXTE</i> /PCA <sup>f,h</sup>	57	...	...	...	...	...	6.8	...
53140.51	<i>RXTE</i> /PCA <sup>f</sup>	54	...	...	...	...	...	6.8	...
53200.14	<i>RXTE</i> /PCA <sup>f</sup>	33	...	...	...	...	...	6.8	...
53295.11	<i>RXTE</i> /PCA <sup>f</sup>	38	...	...	...	...	...	6.8	...
53479.79	<i>RXTE</i> /PCA <sup>f</sup>	94	...	...	...	...	...	6.8	...
Observations with focusing X-ray telescopes:									
52197.61	<i>Chandra</i> /ACIS-I	...	1.1	1.3	$4.2 \pm 1.0$	$0.62 \pm 0.23$	...	...	...
51248.16	<i>ASCA</i> /GIS <sup>i</sup>	...	<0.09	<0.11	...	...	...	...	[2]

<sup>a</sup>Counts/s equivalent for all five detectors of the *RXTE* PCA, top xenon layer only, 2–10 keV.

<sup>b</sup>The uncertainties on the photon and energy fluxes are generally dominated by instrument calibration rather than counting statistics and are on the order of 10%.

<sup>c</sup>From a fit in the energy range 2–10 keV only.

<sup>d</sup>[1] Smith et al. (1998b); [2] Sakano et al. (2002); [3] Sguera et al. (2005); [4] Sunyaev et al. (2003), Smith et al. (2003b), Rupen, Mioduszewski, & Dhawan (2003), Lutovinov et al. (2005); [5] Lutovinov et al. (2005).

<sup>e</sup>Detected during periodic *RXTE* pointings to the nearby source 1E 1740.7–2942.

<sup>f</sup>Detected during periodic *RXTE* scans of the Galactic Bulge.

<sup>g</sup>These three *Integral* outbursts may also be considered part of a single episode of activity containing a wide dynamic range of variability.

<sup>h</sup>These observations took place just after one of the major outbursts observed by *Integral*/IBIS.

<sup>i</sup>The values are  $3\sigma$  upper limits. The energy range for the unabsorbed flux is not specified in Sakano et al. (2002).

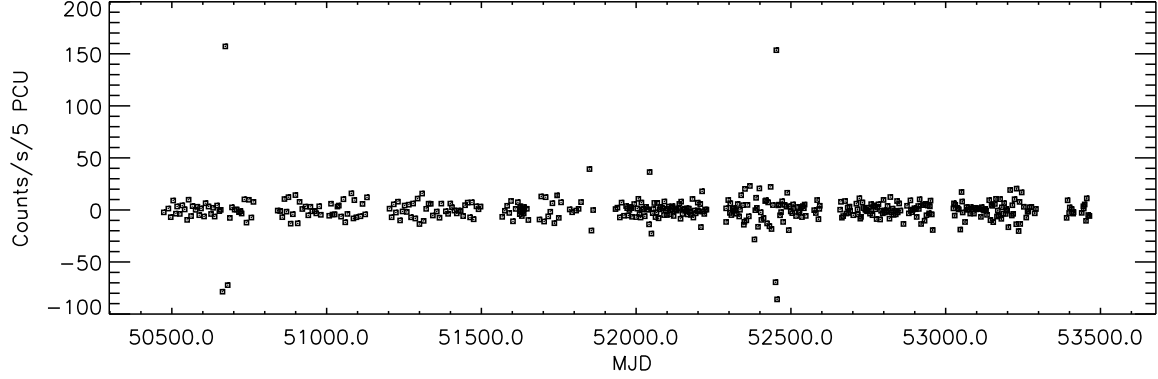


Fig. 1.— Differential lightcurve for the 1E 1740.7–2942 pointings with *RXTE*. The background-subtracted count rate over the full PCA energy range is shown, scaled to the equivalent value if all 5 PCU detectors were turned on (typically from one to three actually were), and uncorrected for the  $\sim 20\%$  collimator response due to the pointing direction. To enhance the visibility of abrupt changes, we subtracted from each point the average of its neighbors; this also results in the negative points on either side of the two bright outbursts. Only pointings with another observation occurring within two weeks in both directions were included.

TABLE 2  
OPTICALLY THIN THERMAL BREMSSTRAHLUNG FITS, 2.5–25 keV, *RXTE* PCA

MJD	$n_H$ ( $\times 10^{22} \text{ cm}^{-2}$ )	$kT$ (keV)	bolo. lum. ( $\times 10^{36} \text{ erg s}^{-1}$ )
50672.707	$6.2 \pm 0.2$	$21.6 \pm 0.8$	5.6
51849.233	$32 \pm 3$	$15 \pm 2$	2.6
52452.930	$7.9 \pm 0.3$	$18.6 \pm 0.8$	4.9

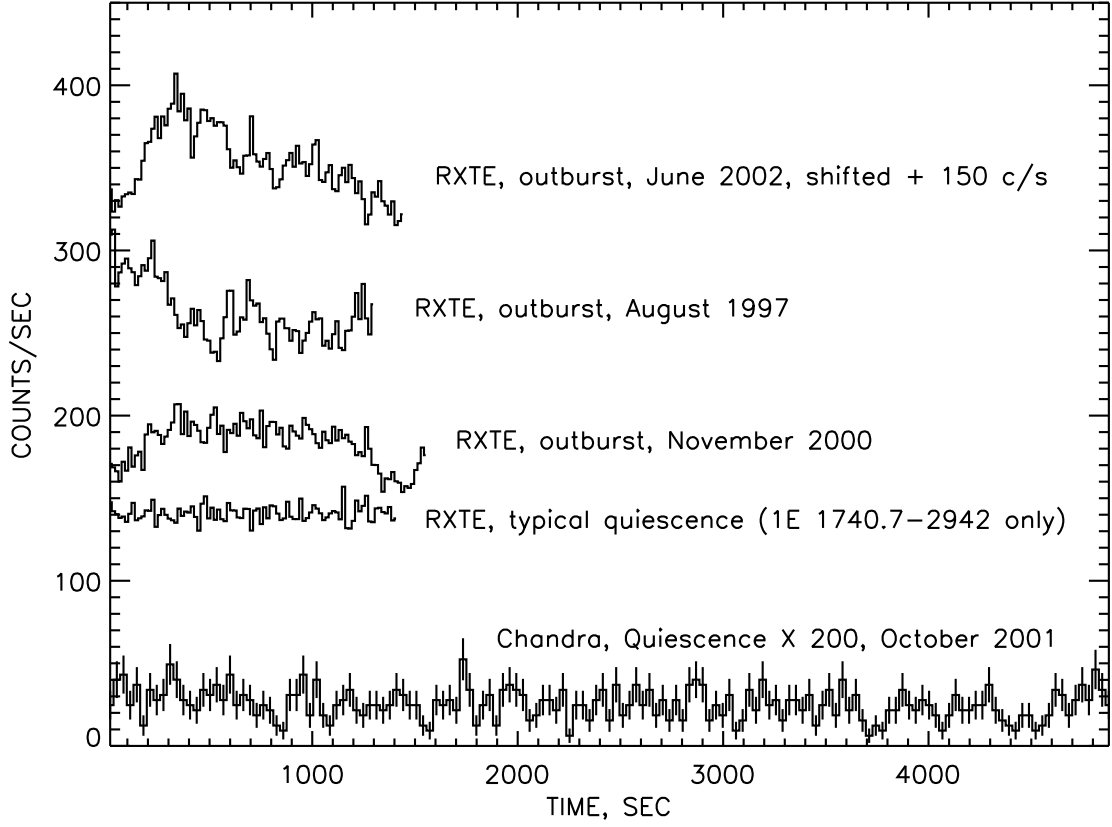


Fig. 2.— Lightcurves of three individual outbursts of XTE J1739–302 from the 1E 1740.7–2942 pointings (top three traces, with the flux from 1E 1740.7–2942 still present), a typical 1E 1740.7–2942 lightcurve when XTE J1739–302 is quiescent, and the lightcurve of XTE J1739–302 as seen at a low level of activity with *Chandra*. The *Chandra* trace is multiplied by 200 to be seen on this scale, and the 2002 outburst has been shifted upward by 150 counts  $\text{s}^{-1}$ .

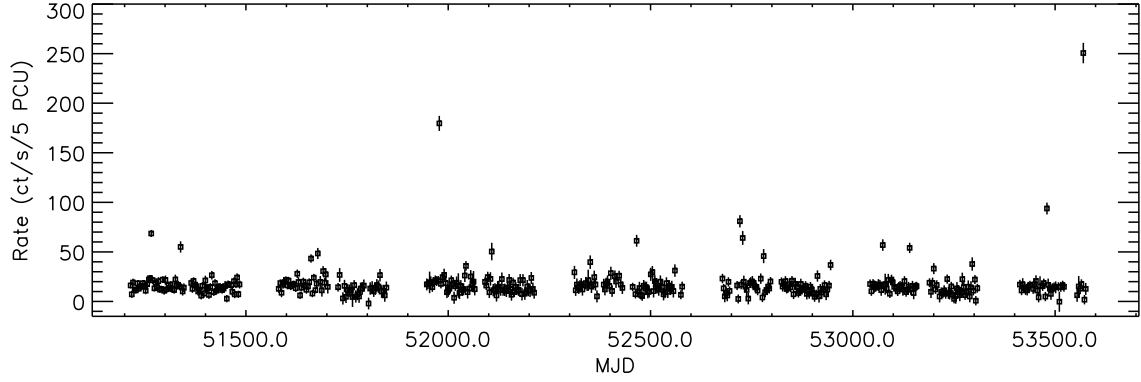


Fig. 3.— Lightcurve of XTE J1739–302 from the *RXTE* Galactic bulge scans. Like Figure 1, the data shown are equivalent count rates for all 5 PCA detectors, but here the count rate shown is from 2–10 keV (typically well over half of the total rate), and the count rates are for 100% collimator response (no pointing offset).

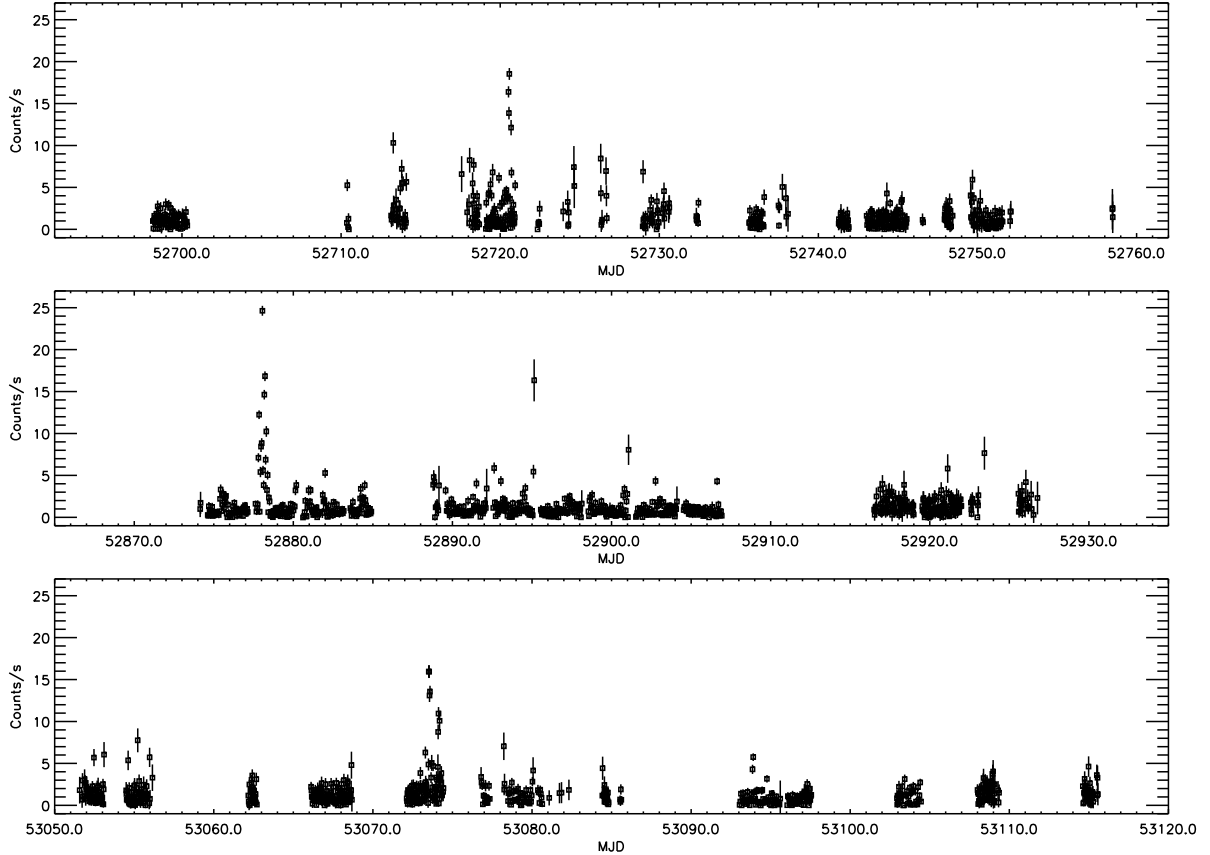


Fig. 4.— *Integral* IBIS/ISGRI lightcurves for XTE J1739–302 for three observing seasons, 13–71 keV. These data are publicly available from the *Integral* Science Data Centre online archive, listed under the source name IGR J17391–3021. Five data points with extremely large error bars ( $> 3$  counts per second) have been removed.

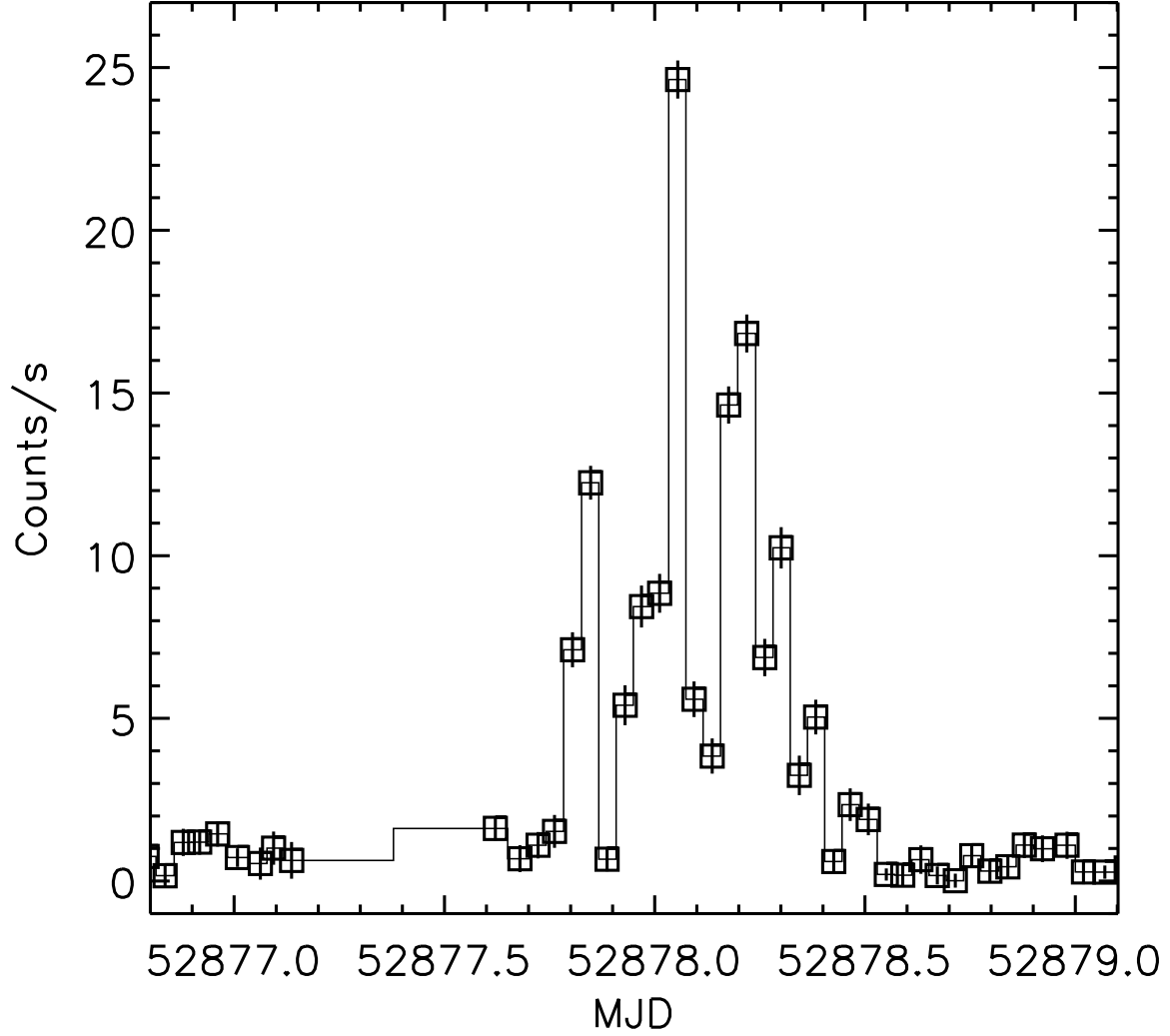


Fig. 5.— IBIS/ISGRI lightcurve for the most complicated and brightest of the *Integral* outbursts of XTE J1739–302 (Sunyaev et al. 2003a), showing extreme variability similar to that seen on an even shorter timescale by *ASCA* (Sakano et al. 2002).

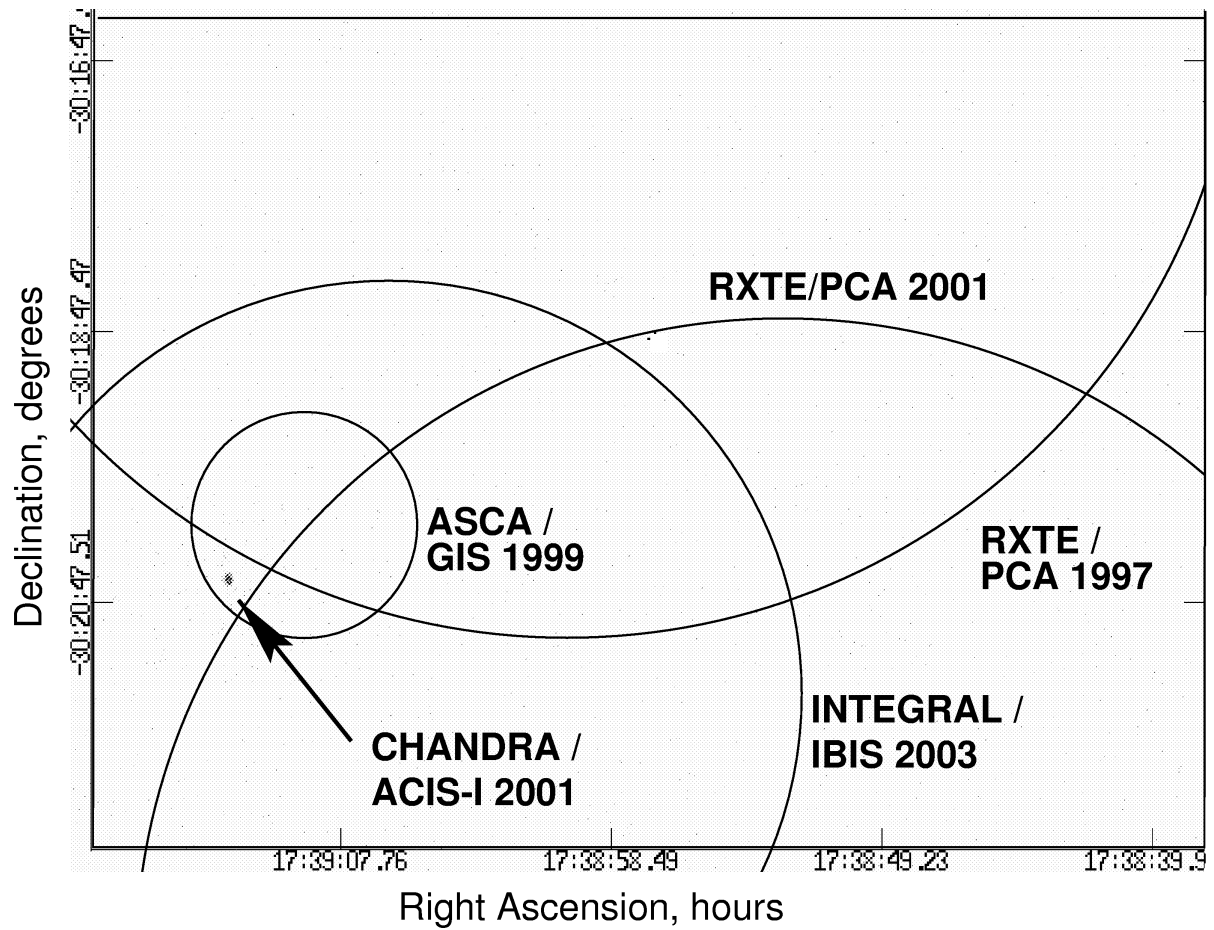


Fig. 6.— Localization circles for XTE J1739–302 from *RXTE*, *ASCA*, and *Integral* superimposed on part of the *Chandra* image field. All the circles are consistent or nearly consistent with the *Chandra* source (see text).

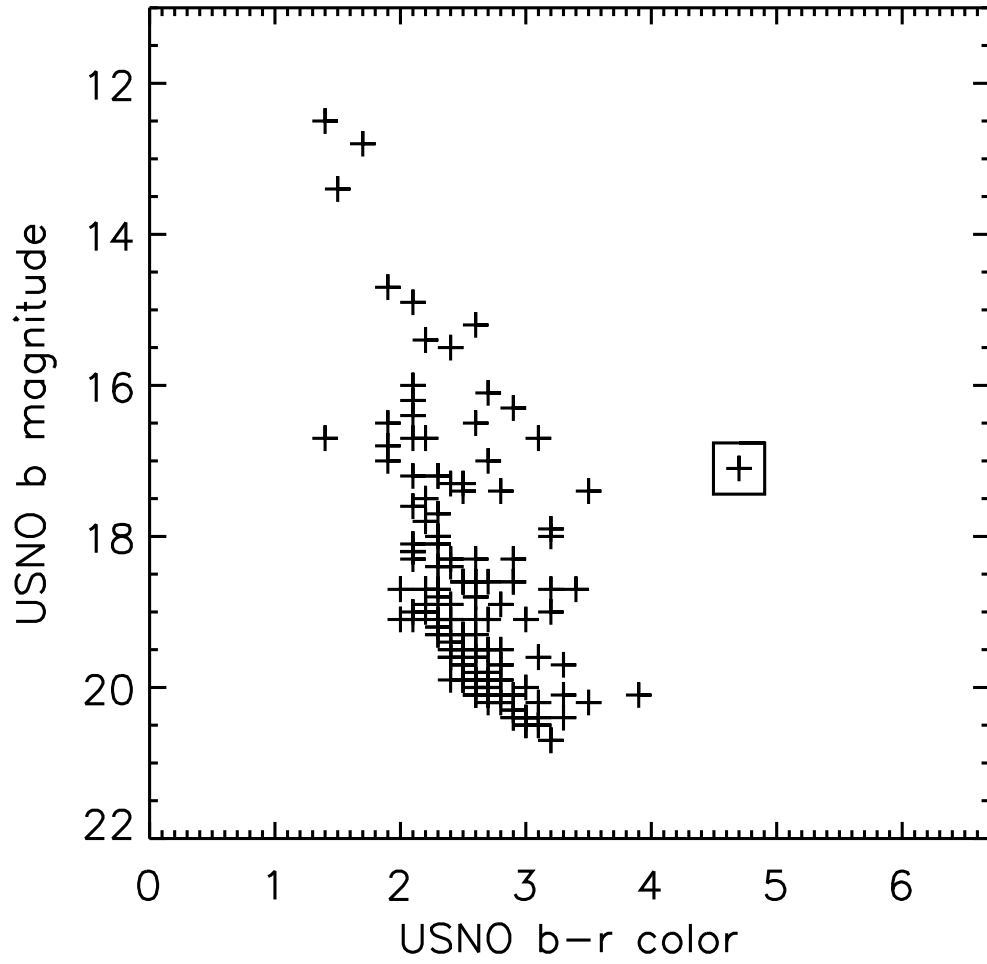


Fig. 7.— Raw color/magnitude diagram (uncorrected for absorption) of USNO A2.0 stars within  $1'$  of XTE J1739–302. The square marks the star that matches the *Chandra* position.

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